Prediction of potentially significant fish harvest using metrics of accessibility in northern Western Australia

PAUL G CLOSE [1], REBECCA J DOBBS [1], TOM J RYAN [1], KARINA RYAN [2], PETER C SPELDEWINDE [1] & SANDY TOUSSAINT [1,3]

[1] *Centre of Excellence in Natural Resource Management, The University of Western Australia, Albany, WA 6330, Australia*

[2] *Western Australian Fisheries and Marine Research Laboratories, Department of Fisheries, Hillarys, WA 6025, Australia*

[3] *Anthropology and Sociology, The University of Western Australia, Crawley, WA 6009, Australia*

✉ *paul.close@uwa.edu.au*

Management of freshwater fisheries in northern Australia faces challenges that combine Aboriginal and recreational harvests, intermittent river flows and remote, expansive management jurisdictions. Using relationships between fishing pressure (vis-à-vis 'accessibility') and the abundance of fish species targeted by Aboriginal and recreational fishers (derived from the Fitzroy River, Western Australia), the potential fishing pressure in subcatchments across the entire Kimberley region was assessed. In addition to the Fitzroy and Ord River, known to experience substantial fishing pressure, this assessment identified that subcatchments in the Lennard and King Edward river basins were also likely to experience relatively high fishing activity. Management of freshwater fisheries in the Kimberley region prioritises aquatic assets at most risk from the potential impact of all aquatic resource use and employs barramundi (*Lates calcarifer*) and silver cobbler (*Neoarius midgleyi*) as indicator species to track changes in their condition. Extending the existing monitoring of these indicator species (currently undertaken in the Ord and Fitzroy rivers) to include popular fishing areas in subcatchments of the Lennard and King Edward river basins will provide a better understanding of the current fishing pressure and its impact on the fisheries resource in the Kimberley region, as well as confirmation of the proposed method's predictive capability for this region. The ability to predict those areas that may experience increased fishing pressure in the future, offers an opportunity for the early monitoring and detection of any changes in the fisheries resource.

KEYWORDS: fisheries management, customary harvest, recreational fishing, Kimberley, intermittent rivers

INTRODUCTION

Rivers of northern Australia support high-value customary and recreational fish stocks (Toussaint *et al.* 2005; Pannell 2010; Toussaint 2010, 2014; Morgan *et al.* 2011; Jackson *et al.* 2012; Close *et al.* 2014). Fish contribute significantly to both Aboriginal household budgets, by providing an important food source for general consumption and during ceremonial events (e.g. Toussaint 2014), and the regional tourism-based economy (Altman 1987; Carson *et al.* 2009). Management of these fisheries faces a unique set of challenges that combine Aboriginal and recreational harvest (Jackson *et al.* 2012; Close *et al.* 2014; Toussaint 2014), intermittent river flows that restrict fish to disconnected refugia (Magoulick & Kobza 2003; Bunn *et al.* 2006; Carini *et al.* 2006; Beesley & Prince 2010; Sheldon *et al.* 2010) and remote, expansive management jurisdictions (Dale *et al.* 2014).

In Western Australia, the Department of Fisheries applies an Ecosystem Based Fisheries Management (EBFM) approach to assess the sustainability of fish stocks and determine the priorities for resourcing within six bioregions (DoF 2011). The EBFM approach acknowledges the links between fished resources and habitat, and through the Finfish Resource Assessment Framework (DoF 2011) indicator species are identified and monitored; the status of these indicators is assumed to represent the status of the resource (asset). The Kimberley region is incorporated into the North Coast and Northern Inland Bioregions for which barramundi *Lates calcarifer* (Bloch 1790) and silver cobbler *Neoarius midgleyi* (Kailola & Pierce 1988) are recognised as indicator species, and the risk of aquatic resource use to the sustainability of 'sooty grunter' (in the Kimberley region = Jenkins' grunter or western sooty grunter, *Hephaestus jenkinsi* (Whitley 1945)) is considered relatively high (DoF 2011). Within the Northern Inland Bioregion, Lake Argyle supports Western Australia's only commercial freshwater fishery, and recreational fisheries for barramundi and cherabin *Macrobrachium rosenbergii* (De Man 1879) are also included in the EBFM for this Bioregion (Newman *et al.* 2013).

Recent research conducted in the Kimberley region of north western Australia suggested that significant overlap/sharing of the fisheries resource exists between Aboriginal and recreational fishers, especially of targeted species including barramundi and Jenkins' grunter (Toussaint 2010; Jackson *et al.* 2012; Close *et al.* 2014). As noted by Close *et al.* (2014), the distinction between recreational and customary harvest is imprecise. Aboriginal people will fish for both recreational purposes as well as those inspired by customary law and practice. In some areas fishing sites are also shared, particularly in the Fitzroy River catchment where most fishing activities (both Aboriginal and recreational) are concentrated in permanent river pools of the main river channel (Jackson *et al.* 2012; Close *et al.* 2014). This concentration of fishing pressure at easily accessible sites has the potential to reduce the abundance of target species, especially

barramundi and Jenkins' grunter (Close *et al.* 2014), species commonly used as bait (e.g. bony bream *Nematalosa erebi* (Günther 1868) and spangled perch *Leiopotherapon unicolor* (Günther 1859)) to catch larger predatory species, and sawfish *Pristis pristis* (Linnaeus 1758), which are targeted by Aboriginal fishers and regularly caught (but not targeted) by recreational fishers (Thorburn *et al.* 2007; Morgan *et al.* 2011).

Tourism and recreational activities (amongst other disturbances) have been identified as potential threats to the sustainability of rivers in northern Australia (e.g. Pusey 2011). The potential for over-exploitation of fisheries resources is likely to be a major consequence of this threat (Pusey *et al.* 2004; Pusey & Kennard 2009; Close *et al.* 2014). Although current regulations govern harvest of fish by Aboriginal and recreational fishers in Western Australia (see Close *et al.* 2014), compliance with these regulations is only monitored during the peak tourism period between May and October in the Fitzroy and Ord rivers, due to the seasonal access and the high number of campers and fishers that visit these areas, and because these catchments are known to be important breeding areas for barramundi. Early detection of any changes in the fisheries resource may be enhanced if those areas currently subjected to high fishing pressure, or likely to experience significant fishing pressure in the future, can be predicted.

Using relationships derived from the Fitzroy River, Western Australia, between fishing pressure (vis-à-vis 'accessibility') and the abundance of fish species targeted by Aboriginal and recreational fishers (Close *et al.* 2014), we provide a preliminary assessment of potential fishing pressure across the entire Kimberley region. In the absence of any comprehensive alternative data, we also provide a simple comparison of those subcatchments predicted to experience significant fishing pressure, with those known to be popular with fishers across the region. We briefly discuss the implications of these results for ecosystem-based fisheries management currently implemented across the Kimberley region.

METHODS

The Kimberley region of Western Australia covers 425 000 km^2, and is bounded by the Indian Ocean in the north-west, the Northern Territory in the east and the Great Sandy Desert in the south. The region includes 10 major drainage basins (Figure 1) within the Kimberley and Northern provinces defined by Unmack (2013) and based on the biogeography of Australian freshwater fishes. Those river basins in the Kimberley Province include the Fitzroy, Keep, Drysdale, Prince Regent, Isdell, King Edward and Lennard. The Pentecost and Ord river basins form the western most extent of the Northern Province, which extends east to approximately Cairns and includes all river basins draining northern Australia, including the Wet Tropics Region of Far North Queensland. The Cape Leveque Coast basin, which contains no large rivers, overlaps the boundary between the Kimberley Province (to the east) and the Paleo Province (to the west).

The Kimberley contains six major population centres: Kununurra and Wyndham in the north east, and Halls Creek, Fitzroy Crossing, Derby and Broome in the south and west (Figure 2). There are only two main transport routes within the region, the Great Northern Highway (GNH) and the Gibb River Road (GRR) that traverse the Kimberley from east to west (Figure 2). An additional two transport routes provide access during the dry season to Kalumburu and the Dampier Peninsula via the GRR and the GNH respectively (Figure 2). The GNH traverses the Fitzroy River basin crossing, or running close to, the lower and middle reaches of the Fitzroy River, the lower reaches of the Margaret River and mid

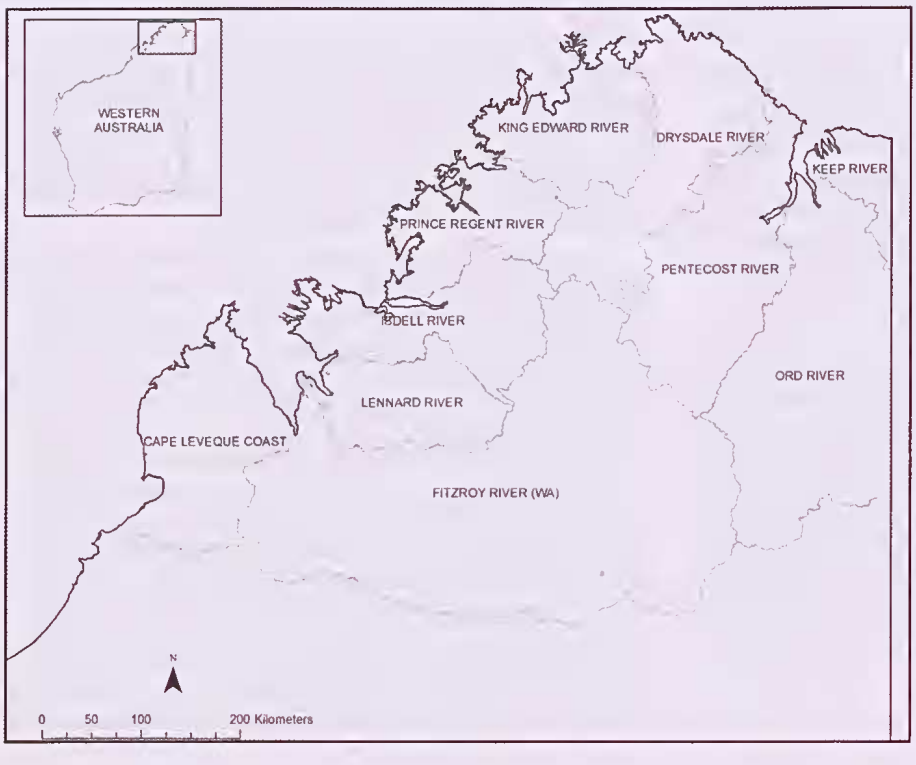

Figure 1 Major river basins in the Kimberley region of northern Western Australia.

reaches of the Mary River. It also provides access to the Ord River basin (Dunham River, upper and lower Ord River). The GRR passes through approximately 180 km of the Lennard River catchment and crosses through the Pentecost River basin providing access to the Pentecost, Durack and Chamberlain rivers and their tributaries. Unsealed over much of its length, the GRR is closed for most of the wet season, except for all-weather sections at either end, which provide access to the Pentecost River from the east and the May River from the west for most of the year. The road to Kalumburu passes through the centre of the King Edward River catchment and also provides access to the Drysdale River during the dry season only. The Cape Leveque Road provides access to coastal waters.

Approximately 40% of the region's population is Aboriginal (ABS 2011). Major communities (populations of over 50 people) (Figure 3) are distributed: in the west

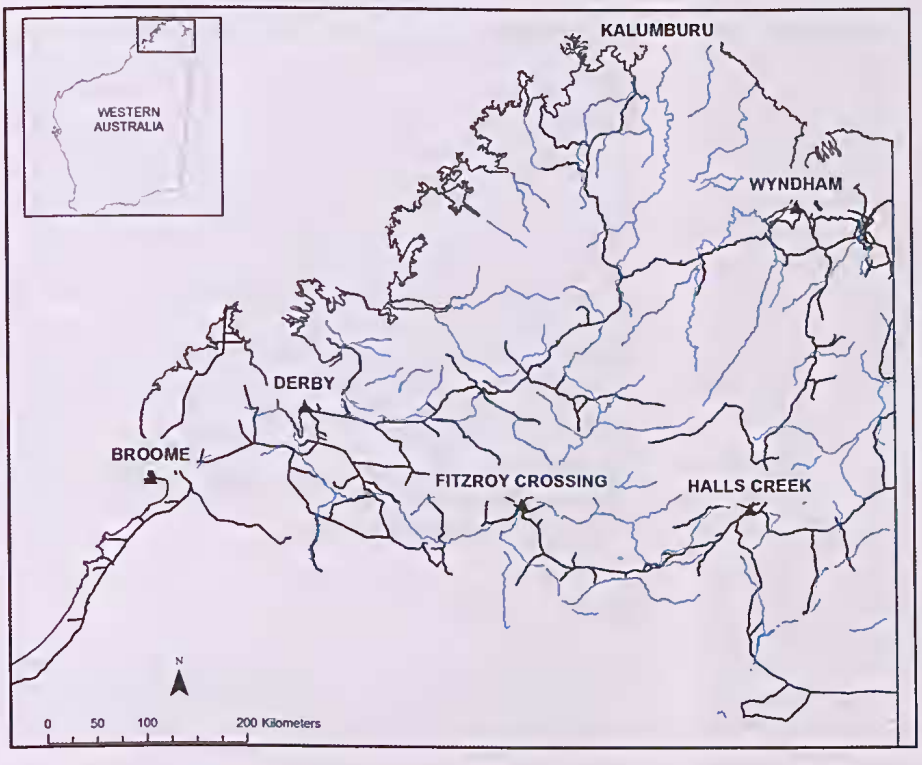

Figure 2 Rivers (—), roads (—), and major population centres (▲) in the Kimberley region of northern Western Australia.

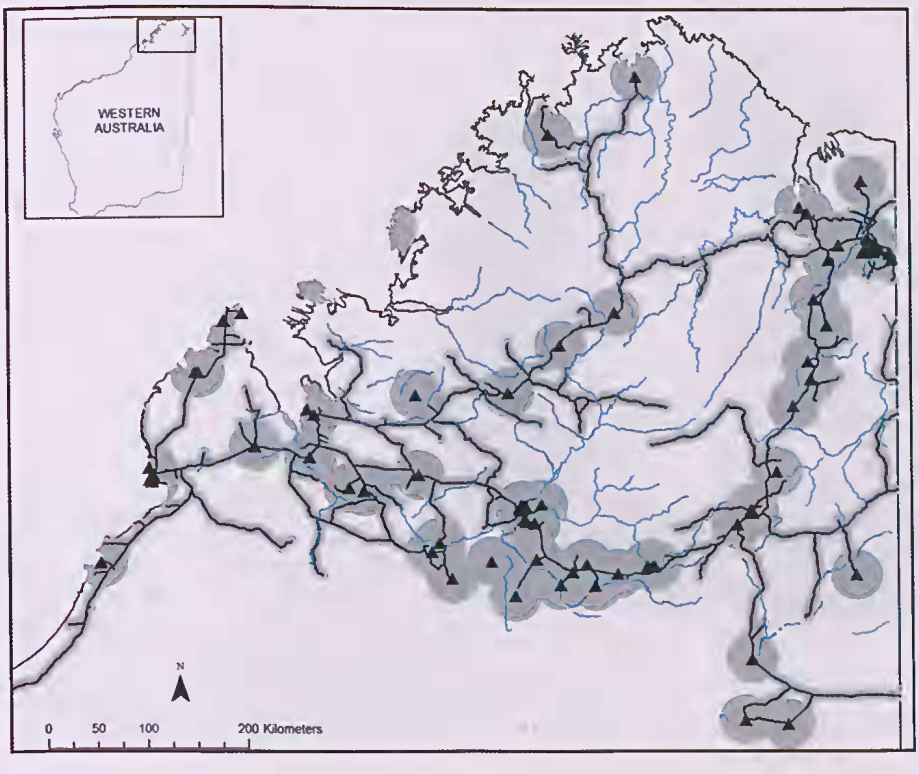

Figure 3 The distribution of 'accessible' areas (■), based on proximity to regional towns, Aboriginal communities (▲), roads and road crossings, that are likely to experience high fishing pressure.

along the GNH (Fitzroy River), the GRR and on the Dampier Peninsula; in the east around Halls Creek and the Ord River; and in the North around Kalumburu.

Four metrics of accessibility, which infer the potential combined Aboriginal and recreational 'fishing pressure', were quantified using GIS (Graphical Information Software; Arcmap V10): linear distance to the nearest road, river distance to nearest road crossing, linear distance to nearest community, and road distance to nearest regional town. These metrics were identified by Close *et al.* (2014) as suitable metrics to quantify fishing pressure. To model potential fishing pressure across the Kimberley region, these metrics were mapped using GIS by applying a 25km buffer around population centres and a 5km buffer either side of roads (following Close *et al.* 2014; Figure 3). These buffers provide a map of 'accessibility' across the region (areas within the buffer were considered accessible and those outside were considered inaccessible). The percentage of 'accessible' river length within subcatchments was then calculated. This method assumes that the relationship between fishing pressure and abundance of targeted species developed from the Fitzroy River (Close *et al.* 2014) is applicable across the region. This is considered justifiable as most rivers in the region share the same targeted freshwater fish as those in the Fitzroy River (Morgan *et al.* 2011).

RESULTS

The spatial analysis of accessibility metrics (Figure 4) indicates subcatchments where accessibility to the river channel may potentially result in increased fishing pressure. River basins (*c.f.* Figure 1) that contain subcatchments with relatively high accessibility include the Fitzroy, Lennard and Isdell river basins in the west Kimberley, the King Edward River basin in the north Kimberley and the Ord and Keep river basins in the east Kimberley (Figure 4). The Cape Leveque Coast basin is also identified as highly accessible, however, as there are no major rivers in this area and the abundance of targeted species is very low (unpublished data), fishing activity targeting freshwater species is presumed low. In all other river basins (*c.f.* Figure 1) spatial analysis predicted that accessibility to major river channels is limited (Figure 4).

In the Fitzroy River basin, the lower reaches of the Fitzroy River downstream of Fitzroy Crossing, the Margaret River, as well as the Mary River are accessible. Upstream of Fitzroy Crossing, accessibility to the main drainages including the O'Donnell, Leopold and Fitzroy rivers is limited, except in the basin's upper most reaches where sections of the Hann River can be accessed. Most of the Lennard River basin, including the May, Lennard and Barker river subcatchments are accessible with exception of the Broome Creek subcatchment. Most of the Isdell River basin is difficult to access, with the exception of the upper reaches of the Isdell River and its tributaries. Most of the King Edward River basin is accessible, especially the upper reaches of the King Edward River, Mitchell River, Camp Creek and the mid-lower reaches of the Carson River. Most of the Western Australian part of the Ord River Basin is accessible, especially downstream of Lake Argyle. Similarly, river reaches of the Keep River basin within Western Australia are identified as being accessible.

DISCUSSION

Overexploitation in freshwater fisheries is largely unrecognised (compared to marine fisheries), poorly documented and, because fishery declines are often

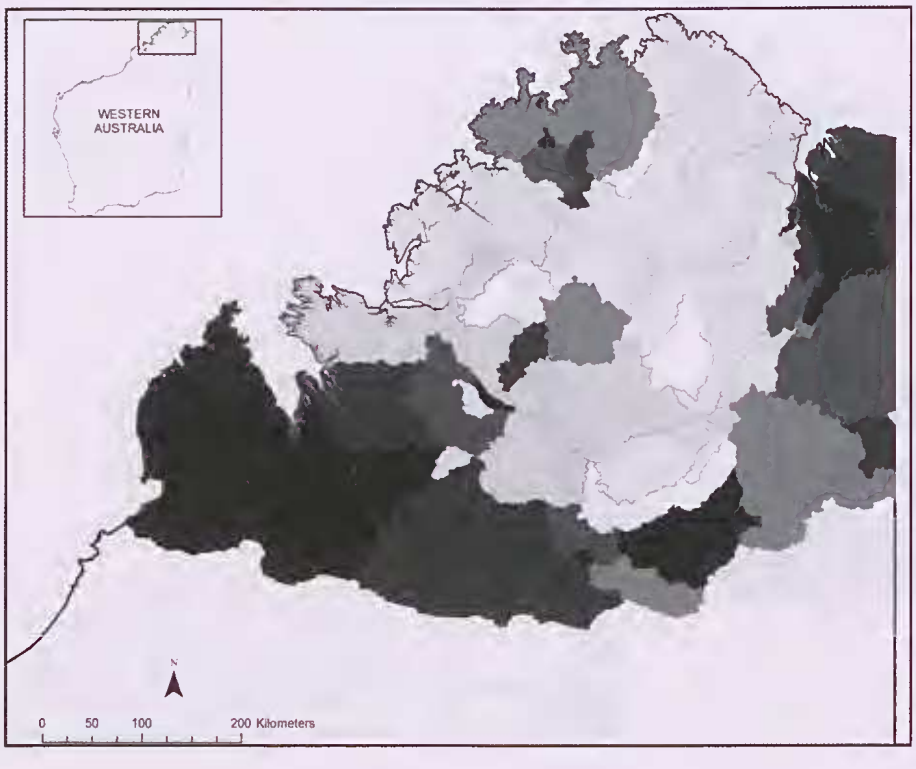

Figure 4 The likely fishing pressure in subcatchments, based on the percentage of 'accessible' river length within each subcatchment. Shading depicts an arbitrary gradient from accessible sites with potentially high fish pressure (black) to inaccessible sites with potentially low fishing pressure (no shading).

confounded with other pressures such as habitat loss and environmental degradation, the effects on sustainability remain poorly understood (Cooke & Cowx 2004; Allan *et al.* 2005). Considering the limited anthropogenic disturbance in the Kimberley region (Stein *et al.* 2002; *c.f.* Vörösmarty *et al.* 2010), there is an opportunity to compile comprehensive baseline data on the current state of local fisheries and investigate potential monitoring programs to detect any changes in habitat availability and fish abundance at appropriate scales for management, policy development and regional knowledge.

Such information is likely to benefit management of freshwater fisheries across the Kimberley (and other regions of northern Australia) as the extent of the region's river channels that are subject to concentrated fishing pressure (such as increasing numbers of recreational fishers) is likely to increase as the region becomes more accessible (due to infrastructure, i.e. road networks, and increased tourism ventures including helifishing and luxury cruise boats that are already accessing freshwater systems via the coastline). The effect of fishing on the abundance of targeted species may also increase, especially in systems where climate-related changes to groundwater recharge may reduce the number, persistence and/or size of permanently watered river pools that provide dry-season refugia for those species harvested (see Close *et al.* 2014).

Monitoring of fisheries resources in the Kimberley and compliance of fishers to regulations is problematic. In the absence of any available data, evidence supporting the predictions of river reaches subject to potentially high fishing pressure is limited to 'local knowledge'. In general, our predictions are consistent with those areas known anecdotally to be popular with Aboriginal and/or recreational fishers. In contrast, although the Pentecost river basin was shown to have limited accessibility (Figure 4), the Pentecost and Chamberlain rivers are popular fishing places for Kimberley locals and tourists. Conversely, the Keep River Basin showed high accessibility, but there is known to be limited fishing in the smaller coastal tributaries that dominate that part of the basin shown in Figure 4, with most of the fishing activities taking place in the Keep River main channel located in the Northern Territory. Similarly, some subcatchments located in the upper reaches of the Fitzroy, Isdell and Lennard Rivers were identified as highly accessible. To our knowledge there are few large permanent waterholes (and probably low abundance of target species) in each of these areas. Whether this results in relatively low fishing pressure, or a concentration of fishing pressure in permanent waterholes, is unknown.

Management of freshwater fisheries has typically focused on the effects of commercial and recreational fishing in 'trophy' fisheries, e.g. the Murray cod in the Murray Darling Basin (Humphries & Winemiller 2009). Remote and intermittent rivers present significant challenges for natural resource managers, due to difficulties in implementing protective policies and legislation in remote areas (Datry *et al.* 2014) and because applicability and transferability of resource monitoring, stock assessment, and development of fisheries management regulations in rivers with intermittent flow, and where the predominant harvest is customary and recreational, is largely unknown.

Fisheries management regulations are driven by specific policy requirements and with an understanding of the nature of the fishery and the spatial and temporal scales of the resource. Monitoring programs or survey designs are therefore customised for specific management objectives (Hartill *et al.* 2012), which may be catch, biological, social or economic in nature. The EBFM approach currently implemented in the Kimberley region includes monitoring of indicator species (i.e. barramundi and silver cobbler) in the Ord and Fitzroy river basins and focuses on an assessment of compliance with regulations that govern the harvest of fish by Aboriginal or recreational fishers in Western Australia. The EBFM approach employed in Western Australia is ideally suited to include a variety of monitoring techniques to quantify the resource use and changes in the condition of ecosystem components, including for example, habitats and the abundance of targeted fish species. Extending current monitoring to include i) popular fishing areas in subcatchments of the Lennard and King Edward river basins and ii) additional information on actual fish harvest and the abundance of targeted fish species, will provide a better understanding the current fishing pressure and its impact on the fisheries resource, as well as confirmation of the proposed method's predictive capability for this region. Options for providing the additional data to inform management of fisheries across the region could include one-off surveys or long-term monitoring of target fish communities, using fisheries dependent and/or independent monitoring techniques, to provide information on either absolute (e.g. total catch) or relative (e.g. catch indices) estimates of fish harvest. Assessment of the distribution of fishing activities and the likely 'pressure' (e.g. number of fishers, number of fish caught) using either on-site and/or off-site surveys of fishers would also be beneficial. Sampling designs need to be at appropriate spatial and temporal scales, with appropriate replication to achieve required precision, to inform changes in harvest levels, decision-making and policy development.

Additional knowledge on 'site-choice' by both Aboriginal and recreational fishers could also contribute valuable information to the EBFM. While some data on the dynamics of Aboriginal use of permanent river pools exists from northern Australia (Jackson *et al.* 2012), similar information that indicates the use of these areas for recreational fishing is limited. Knowledge of the factors that determine 'site choice' by fishers utilising freshwater ecosystems is generally scarce, despite its importance to the development of effective management. Knowing why fishers fish where they do, for example, would refine the prediction of areas currently experiencing high fishing pressure, and those areas that may be subject to high fishing pressure in the future. Important criteria for site choice identified in previous studies include: cost (i.e. travel cost); fishing quality (e.g. size and abundance of target species); environmental quality (terrestrial aesthetics and water quality); facility development (boat ramps and accommodation); encounter levels (i.e. with other anglers), and; fishing regulations (e.g. site or seasonal closures) (see Hunt & Ditton 1997; Schramm *et al.* 2003; Hunt 2005). Nonetheless, in the context of the Kimberley, which is largely only accessible during the dry-season, accessibility may be expected to determine much of the spatial dynamics of fishing pressure (Close *et al.* 2014).

CONCLUSION

In an area as vast and difficult to access as the Kimberley region of Western Australia, knowledge of those areas that are easily accessed and therefore likely to experience higher fishing activity than more remote areas, should provide opportunities to prioritise areas for monitoring and management of the fisheries resource and other ecosystem assets. Using relationships between site accessibility and the abundance of large-bodied fish species developed from the Fitzroy River catchment, this Kimberley-wide assessment of potential fishing pressure identified that subcatchments in the Fitzroy, Lennard, King Edward and Ord river basins are likely to experience relatively high fishing activity. In the context of the Kimberley region, subcatchments may provide an appropriate spatial scale for management; within the basins listed above, subcatchments in the Lennard and King Edward river basins represent potential areas to which the ecosystem based fisheries management approach used in Western Australia could be extended. A variety of monitoring programs could be included in the EBFM approach at these sites to quantify, not only the use of aquatic resources by Aboriginal and recreational fishers, but also the condition of ecosystem assets such as the abundance of targeted species.

ACKNOWLEDGEMENTS

We are grateful for the support of each authors institution during the preparation of this manuscript: the Centre of Excellence in Natural Resource Management, The University of Western Australia and the Department of Fisheries, Western Australia. We thank the organising committee of the inaugural symposium on 'Western Australian Freshwater Fish', especially David Morgan, Stephen Beatty, Michael Snow and Debra Thomas, for the opportunity to present the research on which this manuscript is based. We acknowledge the Australian Society for Fish Biology, the Royal Society of Western Australia, the Department of Fisheries Western Australia, the Government of Western Australia and the Murdoch University, Freshwater Fish Group & Fish Health Unit, that supported the symposium.

REFERENCES

Australian Bureau of Statistics 2011. 2011 Census Quick Stats. Accessed online 20th May 2013. http://www.censusdata.abs.gov.au/census_services/getproduct/census/2011/quickstat/50804?opendocument&navpos=220

Allan D J, Abell R, Hogan Z, Revenga C, Taylor B W, Welcomme R L & Winemiller K 2005. Overfishing of inland waters. *Bioscience* **55**, 1041–1051.

Altman J C 1987. *Hunter Gatherer's Today: An Aboriginal Economy in Northern Australia.* Australian Institute of Aboriginal Studies, Canberra.

Beesley L S & Prince J 2010. Fish community structure in an intermittent river: the importance of environmental stability, landscape factors and within-pool habitat descriptors. *Marine and Freshwater Research* **61**, 605–614.

Bunn S E, Thoms M C, Hamilton S K & Capon S J 2006. Flow variability in dryland rivers: boom, bust and the bits in between. *River Research and Applications* **22**, 179–186.

Carini G, Hughes J M & Bunn S E 2006. The role of waterholes as 'refugia' in sustaining genetic diversity and variation of two freshwater species in dryland river systems (Western Queensland, Australia). *Freshwater Biology* **51**, 1434–1446.

Carson D, Taylor A & Campbell S 2009. *Demographic trends and likely futures for Australia's tropical rivers.* Charles Darwin University, Darwin. ISBN: 978-1-921576-14-0.

Close P G, Dobbs R J, Tunbridge D J, Speldewinde P C, Warfe D M, Toussaint S & Davies P M 2014. Customary and recreational fishing pressure: large-bodied fish assemblages in a tropical, intermittent Australian river. *Marine and Freshwater Research* **65**, 466–474.

Cooke S F & Cowx I G 2004. The role of recreational fishing in global fish crises. *Bioscience* **54**, 857–859.

Datry T, Larned S T & Tockner K 2014. Intermittent rivers: a challenge for freshwater ecology. *Bioscience* **64**, 229–235.

Dale A P, Pressey B, Adams V M, Álvarez- Romero J G, Digby M, Dobbs R, Douglas M, Augé A A, Maughan M, Childs J, Hinchley D, Landcaster I, Perdrisat 1 & Gobius N 2014. Catchment-scale governance in Northern Australia: a preliminary evaluation. *Journal of Economic and Social Policy* **16**, issue 1 article 2.

Department of Fisheries 2011. *Resource Assessment Framework (RAF) for Finfish Resources in Western Australia.* Fisheries Occasional Publication No. 85. Department of Fisheries, Western Australia. 28 pp.

Doupé R G, Morgan D L & Gill H S 2005. Prospects for a restorative fishery enhancement of Lake Kununurra: a high-level tropical impoundment on the Ord River, Western Australia. *Pacific Conservation Biology* **11**, 136–146.

Hartill B W, Cryer M, Lyle J M, Rees E B, Ryan K L, Steffe A S, Taylor S M, West L & Wise B S 2012. Scale- and context-dependent selection of recreational harvest estimation methods: the Australasian experience. *North American Journal of Fisheries Management* **32**, 109–123.

Humphries P & Winemiller K O 2009. Historical impacts on river fauna, shifting baselines, and challenges for restoration. *Bioscience* **59**, 673–684.

Hunt L M 2005. Recreational fishing site choice models: insights and future opportunities. *Human Dimensions of Wildlife* **10**, 153–172.

Hunt K A & Ditton R B 1997. The social context of site selection for freshwater fishing. *North American Journal of Fisheries Management* **17**, 331–338.

Jackson S, Finn M & Featherstone P 2012. Aquatic resource use by Indigenous Australians in two tropical river catchments: the Fitzroy River and Daly River. *Human Ecology* **40**, 893–908.

Magoulick D D & Kobza R M 2003. The role of refugia for fishes during drought: a review and synthesis. *Freshwater Biology* **48**, 1186–1198.

Morgan D, Allen G, Pusey B & Burrows D 2011. Freshwater fishes of the Kimberley region, north-western Australia. *Zootaxa* **2816**, 1–64.

Morgan D L, Allen, M G, Bedford P & Horstman M 2004. Fish fauna of the Fitzroy River in the Kimberley region of Western Australia – including the Bunuba, Gooniyandi, Ngarinyin, Nyikina and Walmajarri Aboriginal names. *Records of the Western Australian Museum* **22**, 147–161.

Morgan D L, Whitty J M, Phillips N M, Thorburn D C, Chaplin J A & McAuley R 2011. North-western Australia as a hotspot for endangered elasmobranchs, with particular reference to sawfishes and the Northern River Shark. *Journal of the Royal Society of Western Australia* **94**, 345–358.

Newman S J, Skepper C, Mitsopoulos G, Thomson A & Carter P 2013. Lake Argyle Silver Cobbler Fishery Report: Statistics Only. *In*: Fletcher W J & Santoro K (eds) *Status Reports of the Fisheries and Aquatic Resources of Western Australia 2012/13: The State of the Fisheries*, pp. 295–296. Department of Fisheries, Western Australia.

Pannell S 2010. *Martuwarra/Mardooworra ('River Country'): A report on the Indigenous Heritage Values of the Fitzroy River Drainage System.* Australian Heritage Commission, Canberra.

Pusey B 2011. *Aquatic Biodiversity in Northern Australia: Patterns, Threats and Future*. Charles Darwin University Press, Darwin.

Pusey B J & Kennard M J 2009. Chapter 3 – Aquatic ecosystems of northern Australia. In: Stone P (ed.) *Northern Australia Land and Water Science Review*. Final report to the Northern Australia Land and Water Taskforce. CSIRO Publishing.

Pusey B J, Kennard M J & Arthington A H 2004. *Freshwater Fishes of North-Eastern Australia*. CSIRO Publishing.

Schramm H L, Gerard P D & Gill D A 2003. The importance of environmental quality and catch potential to fishing site selection by freshwater anglers in Mississippi. *North American Journal of Fisheries Management* **23**, 512–522.

Sheldon F, Bunn S E, Hughes J M, Arthington A H, Balcome S R & Fellows C S 2010. Ecological roles and threats to aquatic refugia in arid landscapes: dryland river waterholes. *Marine and Freshwater Research* **61**, 885–895.

Stein J L, Stein J A & Nix H A 2002. Spatial analysis of anthropogenic river disturbance at regional and continental scales: identifying the wild rivers of Australia. *Landscape and Urban Planning* **60**, 1–25.

Thorburn, D C, Morgan D L, Rowland A J & Gill H S (2007). Freshwater Sawfish *Pristis microdon* Latham, 1794 (Chondrichthyes: Pristidae) in the Kimberley region of Western Australia. *Zootaxa* 1471, 27–41.

Toussaint S 2010. *Fitzroy Valley Indigenous groups and the multi-criteria value of fishing and fish*, unpublished report for the Tropical Rivers and Coastal Knowledge Project, CSIRO, Darwin.

Toussaint S 2014. Fishing for Fish and for Jaminyjarti in Northern Aboriginal Australia. *Oceania* **84**, 38–51

Toussaint S, Sullivan P & Yu S 2005. Water Ways in Aboriginal Australia: an interconnected analysis. *Anthropological Forum* **15**, 61–74.

Unmack P J 2013. Biogeography. In: Humphries P and Walker K F (eds) *The Ecology of Australian Freshwater Fishes*, pp. 25–48. CSIRO Publishing.

Vörösmarty C J, McIntyre P B, Gessner M O, Dudgeon D, Prusevich A, Green P, Glidden S, Bunn S E, Sullivan C A, Reidy Liermann C & Davies P M 2010. Global threats to human water security and river biodiversity. *Nature* **467**, 555–561.